

*Amendments in the Specification*

[0004] Further, for example, the points identified by the sampling plan will dramatically affect the accuracy of the estimation. Many sampling plans include a grid-like array of points having a given spaced-apart relationship. For example, such a grid-like array may be obtained in a "line scan". In order to obtain an accurate estimation of the form, however, a sampling plan may need to include denser grids in some portions of the form, such as in portions of the form having complex shapes. Also, for example, a grid-like sampling plan having predetermined spacing may waste time making measurement in portions of the form that are uncomplicated and thus may be estimated with only a few samples. Additionally, having a sample plan that samples a lot of points in a non-complex portion of the form may increase the variability of the estimate. As such, the development of an accurate sampling plan for a given form may require a high investment in time and cost. Also, the time and cost is further multiplied for every form for which an estimate is required. Thus, the accuracy and completeness of the form estimation, as well as the time required to perform the measurements, is highly dependent on the sampling plan.

[0010] In another embodiment, a method for estimating a relationship between a plurality of points, comprises: generating a first estimated relationship between the plurality of points based on measured coordinate data and normal vector data, the measured coordinate data comprising a measured value of a vector associated with a point corresponding to a given one of the plurality of points, the normal vector data representative of a local rate of change with respect to the vector associated with the given one of the plurality of points, the first estimated relationship between the plurality of points derived from estimated normal vector data corresponding to at least a portion of the plurality of points; [a]and automatically determining whether further measurements are required based on the estimated normal vector data in combination with predetermined measurement criteria.

[0013] In a further embodiment, a computer readable medium for estimating a systematic relationship between a plurality of points, comprises: an estimation module having a predetermined estimation function operative to generate a first estimated systematic relationship between the plurality of points based on coordinate data and normal vector data, the coordinate data comprising a measured value of a vector corresponding to a given one of the plurality of points, ~~the~~ the first estimated systematic relationship between the plurality of points derived from estimated normal vector data corresponding to at least a portion of the plurality of points; and an adaptive sampling module operative to automatically determine whether further measurements are required based on the estimated normal vector data in combination with predetermined measurement criteria.

[0022] Referring to Fig. 1, in one embodiment, a form estimation system 10 for estimating a shape of a form 12 defined by a plurality of points 14 includes an estimator 16 that receives measured or computed position data 18 and measured or computed normal vector data 20 associated with given points on the form and generates an estimated shape 22 based thereon and according to an estimation function 24. Estimation function 24 processes position data 18 ~~position data 18~~ and normal vector data 20, or data error 30 associated therewith, according to a predetermined mathematical model to predict a shape of form 12 based on values associated with the measured or computed points. A measurement device 26 may supply position data 18 and normal vector data 20 to estimator 16. Additionally, estimator 16 may include an adaptive sampling mechanism 28 that determines error 30 associated with the data, determines whether further measurements are required depending on the magnitude of the error, and identifies at least one target point 32 on form 12 for further measurement. Adaptive sampling mechanism 28 is driven by, among other factors, the normal vector data 20, error 30 and a predetermined error limit 34 to automatically make the sampling decision. Further, estimator 16 may include a data verification device 36 for analyzing the measured/computed data or error data with respect to estimated data in order to verify the accuracy of the measured/computed data or error data and remove inaccurate data. Thus,

form estimation system 10 utilizes position data and normal vector data to automatically sample points on form 12 according to adaptive sampling mechanism 28 and to predict the shape of the form 12 according to estimator 16 such that the estimated shape 22 is accurate within predetermined error limit 34.

[0023] Form 12 includes a surface, a waveform, any object, or any physical or artificially-generated phenomenon having a measurable shape or having a systematic relationship between points. Plurality of points 14 includes points that define the surface of form 12. Each of the plurality of points 14 includes associated data that describe the point, including actual position data 38 and actual normal vector data 40. As used herein, the term “position data” includes any coordinate data that can be represented in vector space, such as, in one example, the position of the point in an x-, y- and z-axis coordinate system. The term “normal vector data” includes data representing the magnitude and direction of a vector positioned normal to a line or plane tangentially positioned with respect to a given point on the form, or data that describes or estimates the instantaneous rate of change of the position data. For example, form 12 may be an object that system 10 measures and compares against a desired nominal shape, or the form may have an unknown shape requiring definition by the system.

[0028] Measurement device 26 measures the value of position data and measures or estimates normal vector data at a given point on form 12. Measurement device 26 may include, for example, a coordinate measurement machine (CMM), an oscilloscope, an electronic measurement device, a laser measurement device, an optical measurement device, a mechanical measurement device; devices that measure color, sound, motion, position, temperature, velocity, acceleration and other physical characteristics via mechanical, electrical, electronic, optical, hydraulic sensors; devices that measure simulated signals generated via computer simulation or from data stored in a data base., or any other device capable of measuring and/or estimating the value of position and normal vector data.

[0032] Referring to Fig. 2, one embodiment of a method for estimating the shape of a form having a plurality of points includes identifying a starting set of points on the form for measurement (Block 70). The starting set of points ~~are~~ is evaluated to determine whether or not they meet the predetermined sample spacing limits (Block 72). If the starting set does not meet the limits, such as if the points are too closely spaced or spaced too far apart, then a new starting set of points is generated that meet the spacing limits (Block 74). If the starting set does meet the limits, then the next action may be taken (see Block 76, described below). In one embodiment, the starting set of points defines a boundary of the form, and the starting set comprises at least three non-linear points. As such, the form is covered by a "triangular patch" defined by the three points. In one embodiment, one or more triangular patches are identified to cover the portion of the form of interest, where adjacent triangular patches may share all or a portion of a side of a triangular patch. Once one triangular patch is evaluated using the described methodology, the system moves on to the remaining triangular patches until the entire portion of interest of the form has been evaluated. It should be noted that any number of points may be utilized, from a single point to a plurality of points, with the number of points varying depending on the estimation function utilized. Further, it should be noted that rectangular, square, or any other shaped patches may also be utilized. The method works the same for any type of patch -- the boundaries could be curves, discrete point sets, or any rule sets that describe which points are on the surface and which are not. Further, surface models that have boundaries outside of the zone formed by the sample points may also be used. Alternatively, the starting set of points may comprise a single line, or two or more lines of spaced-apart points, for example a grid-like array of spaced-apart points, such as may typically be utilized in a line scan type of sampling plan. In one embodiment utilizing such a spaced-apart starting set, the triangular patches are chosen from among the plurality of spaced-apart points such that the three points are not co-linear. In such a manner, a portion of a surface perpendicular to an initial line scan may be evaluated.